STEM Fellowship Big Data Challenge 2023-24

Effect of Climate Change on Coral Reefs

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Abstract

As high school students belonging to a time faced with climate change, we take it as our responsibility to put forward our best efforts to bring a solution to unite our ecology to human development. One such environmental concern is ocean acidification - the decrease in ocean pH levels and its impact on coral reefs. Coral reefs remain one of the most valuable marine creatures in our oceans serving as a home for marine life and a buffer against natural disasters. This project delves into the repercussions of ocean acidification on coral reefs, utilizing data analytics to unravel complex ecological dynamics. Focused on ocean characteristics such as pH levels, temperature fluctuations, and carbonate ion concentrations, and coral growth analytics, such as density, height, width, and weight, the study aims to elucidate the nuanced relationships between ocean acidification and coral health. Harnessing machine learning algorithms, I intend to dissect the extensive dataset to reveal patterns, correlations, and predictive models, shedding light on the unique responses of different coral species to changing ocean chemistry. The outcomes of this investigation extend beyond academic curiosity, offering insights into coral reef conservation and management strategies. Through data-driven analysis, this paper aspires to inform targeted interventions and policies that mitigate the adverse impacts of ocean acidification on coral reefs. This interdisciplinary approach emphasizes the need for technological solutions in promoting the resilience of coral ecosystems amid escalating global environmental changes.

Keywords
Ocean Acidification, Coral Calcification, Aragonite Saturation

1 Introduction

Ocean Acidification remains a key issue that pertains around the world today. Delving deeper into the idea, ocean acidification ultimately links back to the overarching concept of climate change. Climate change is a result of an influx in the amount of CO_2 in the atmosphere. This results in the depletion of the ozone layer, and brings about a rise in temperature.

The significant shift in our daily life brought about by industrialization is one of the primary reasons for the sharp rise in CO_2 in the atmosphere. The level of atmospheric CO_2 before industrialization was a startling 220 ppm (parts per million). Nevertheless, the concentration of CO_2 rose to approximately 385 ppm after industrialization [1]. In addition, experts anticipate a startling rise to almost 770 parts per million by the close of the twenty-first century.

This was majorly from the change to fossil fuels, subsequent changes in agricultural practices, and urbanization. CO_2 has always existed on the planet. Under managed levels, the earth has the ability to capture and sequester the CO_2, to maintain an equilibrium. [2] However, modern human development has started to disrupt the natural processes that maintain the balance, ultimately resulting in a rise in CO_2 levels.

This project aims to relate the major ecological concern of today - the CO_2 increase, to marine life, attempting to understand the impacts of CO_2 on coral calcification. Through the project, this paper asks the question: How does an increase in CO_2, when in the ocean, impact the calcification of Sea Coral, and cause a possible obstacle in their growth? The hypothesis revolves around linking the two aspects, focusing on ocean pH levels, ocean aragonite saturation states, and subsequently, coral population. At the same time, this thesis attempts to delve into the effects of environmental changes on sea coral biodiversity using programming languages for a comprehensive analysis, while scrutinizing the interconnected relationships within ecosystems, and offering insights that contribute to the preservation and restoration of fragile marine habitats.

2 Materials & Methods

In order to analyze the impact of CO_2 on marine ecosystems, I used a dataset from the National Centers for Environmental Information's (NCEI) National Coral Reef Monitoring program, called Water Chemistry of the Coral Reefs in the Pacific Ocean [3]. This data was collected at coral reef sites, at the Hawaiian and Mariana Archipelagos, American Samoa, and the Pacific Remote Island Areas, from 2013 to the present. From this dataset, this paper uses the CO_2 concentration, the pH value of the ocean and the aragonite saturation levels. I then analyzed the data, sorted, and filtered the useful variables, and then graphed the dataset using Python v3, along with Numpy, Seaborn, Matplotlib, and Pandas.

The main variables I used from this dataset, were the ocean pH level, ocean CO_2 concentration, and the aragonite saturation state of the coral reef. In order to answer my hypothesis, I attempt to connect the dots between atmospheric CO2, its effects on the ocean, and its subsequent effects on the coral reefs. First, I graphed a scatter plot with the CO_2 concentration, in relation to the ocean pH level, to understand the relation between the two. Next, I graphed a scatter plot to understand the relation between the ocean pH and the aragonite saturation state. Lastly, I used a histogram, to understand the frequency of coral for each aragonite saturation state. I labeled each graph with corresponding titles and labels to finalize my understanding.

3 Results

3.1 Ocean pH levels vs Ocean CO_2

To link the atmospheric CO_2 to its effects on the Ocean, I started by graphing the relationship between the Ocean CO_2 concentration levels in µmol/kg and the ocean pH levels (Figure 1). The correlation score for Figure 1 is -0.9718, which clearly shows a strong negative correlation. This shows that the CO_2 is inversely proportional to the ocean pH. In other words, as CO_2 levels increase the ocean pH decreases, and therefore, the ocean acidity increases.

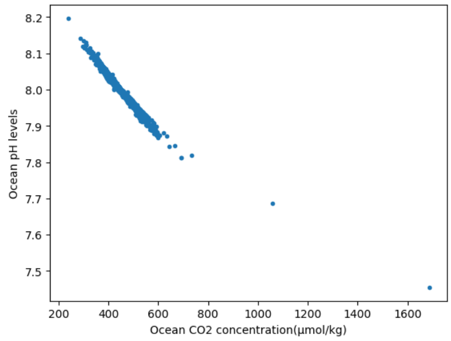

Figure 1: This graph explores the relationship between the Ocean CO_2 concentration in µmol/kg and the Ocean pH levels

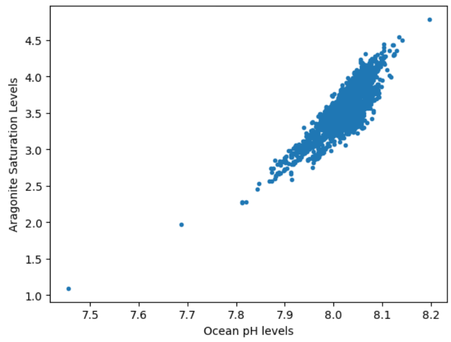

Figure 2: This graph explores the relationship between the Ocean pH levels and the ocean aragonite saturation levels

3.2 Ocean aragonite saturation vs Ocean pH levels

The next step was to link ocean pH to aragonite saturation to connect the ocean to coral calcification. In order to do this, I graphed the ocean aragonite saturation (carbonate ion saturation) in relation to the ocean pH levels. (Figure 2). The correlation score for Figure 2 is 0.847, showing a clear positive correlation between the two, therefore, they are directly proportional. In other words, as the Ocean pH increases, the aragonite saturation state increases. Combining Figure 1 and Figure 2, we find that as the Ocean CO_2 concentration increases, the Aragonite saturation levels decrease.

3.3 Frequency of Ocean Aragonite Saturation Levels

Aragonite remains a key component of the coral reefs. Therefore, to understand the impact of decreasing aragonite levels, we use a histogram to comprehend how different aragonite saturation levels allow for better coral growth. (Figure 3). From the figure, we see that the p05

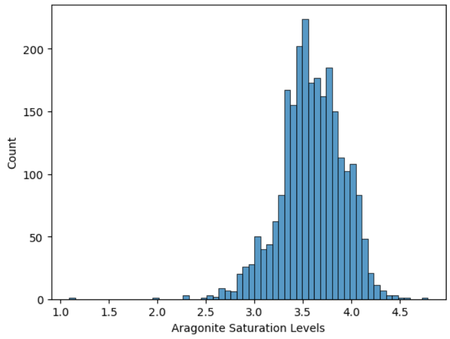

Figure 3: This graph explores the relationship between the Ocean pH levels and the ocean aragonite saturation levels

is 3.05, showing that if aragonite levels decrease below 3.05 there is an extremely low population of coral, and further lower, coral are unable to survive.

Linking this to the above sections, this paper summarizes the results as follows: As the CO_2 concentration in the ocean increases, the ocean pH level tends to decrease, showing an increase in the acidity of the ocean, commonly termed as ocean acidification. As ocean acidity increases, the aragonite (carbonate ion) saturation level decreases, further lowering the opportunity for coral growth.

4 Discussion

4.1 Reasoning

Under normal CO_2 levels, there remains an equilibrium in the ocean. Dissolved CO_2 reacts with water, to form H_2CO_3, Carbonic Acid. This H_2CO_3 further ionizes to form HCO_3, bicarbonate ions, and H^-.Under regular pH levels, this may further ionize to form CO_3, carbonate ions, and H_2. (Equation 1, 2, 3)

$$CO_2 + H_2O \longrightarrow H_2CO_3 \quad (1)$$

$$H_2CO_3 \longrightarrow H^- + HCO_3^+ \quad (2)$$

$$HCO_3^+ \longrightarrow H_2 + CO_3 \quad (3)$$

Coral skeletons are constructed from aragonite, a specific type of calcium carbonate. To reach sunlight, corals meticulously build a framework of aragonite crystals. The process involves coral polyps, minute soft-bodied coral organisms, drawing in seawater that carries ions, including calcium Ca_2^+, into a designated "calcifying space" positioned between their cells and the existing skeletons. [4] Within this space, they actively expel hydrogen ions (H+) to generate additional carbonate ions CO_3. These carbonate ions then bond with calcium ions (Ca) to produce the calcium carbonate $CaCO_3$ essential for their skeletal structures.

However, as the CO_2 concentration increases and changes the equilibrium, there is an increase in Carbonic Acid, and, therefore, an overall decrease in the pH level of the ocean. As the pH level decreases, the bicarbonate (HCO_3) ions are unable to further ionize and form carbonate (CO_3) ions affecting calcium carbonate production, for skeletal structures [5]. This affects the density of sea coral and thus impacts the existence of the sea coral as a whole.

A similar correlation can be seen in the graphs too. As shown in Figure 3, we see a harm to the sea coral population existent in waters with aragonite saturation levels below around 3.05. As suggested by Figure 2, when ocean pH levels tend to fall below around 7.9, its aragonite saturation levels reach 3.05 which, from Figure 3, is harmful to our coral reefs. This occurs, according to Figure 1, when CO_2 levels reach around 750ppm. And this is fast approaching. As research suggests, CO_2 levels are predicted to reach around 750ppm by the end of the 21st century, bringing about aragonite saturation levels of around 3.05, which according to Figure 3 predict that coral reefs may come close to extinction. [1].

4.2 Conservation Strategies

Coral reefs play a vital role in the underwater ecosystem, serving as a significant source of income for millions of individuals and offering protection to coastal areas by diminishing the impact of waves on the shore. The biodiversity thriving within coral reefs is remarkable, with numerous species coexisting in these environments. A single reef can host thousands of species. For instance, the Great Barrier Reef in Australia boasts an impressive array, including over 400 types of coral, 1,500 fish species, 4,000 mollusk species, and six out of the world's seven sea turtle species [6].

Looking back at the chain of reactions that impact the reefs, this paper maps out each possible opportunity for conservation. Starting from CO_2 in the ocean, the ideal way to conserve the species, is to minimize atmospheric CO_2 as a whole. While some of the main causes are fossil fuel consumption, and factory pollution, each and everyone contributes to the global carbon footprint and could make a difference from small changes to one's everyday lifestyle. This includes carpooling, minimizing motor vehicle use, ensuring everyday products' sustainability, minimizing plastic use, properly disposing waste, and range to much more. While such changes might seem absolutely minute, it's every small change that amounts to something big.

Focusing on the other end of the chain - the coral reefs - one possible conservation strategy would be to closely monitor and maintain a large pool of water that imitates the conditions of oceans, to harvest and grow sea coral. This protects the species and ensures their existence while, at the same time, simpler to establish. This is similar to common conservation movements that occur all over the world to protect our ecosystems, including tigers, elephants, elks, turtles, and much more.

Conclusion

The escalating levels of CO_2 in the ocean pose a grave threat to coral reefs, disrupting their delicate equilibrium by hindering the production of essential calcium carbonate. This jeopardizes the very foundation of coral skeletons, as evidenced by the observed decline in coral populations. Urgent conservation strategies are necessary and emphasize the reduction of atmospheric CO_2 through collective efforts and the implementation of controlled environments for coral cultivation.

Recent data highlights the pressing need for action, indicating that CO_2 levels are predicted to reach 750 µmol/kg by the end of the 21st century, bringing about harmful saturation levels for coral reefs. [1] The impending challenge underscores the critical importance of impactful conservation measures. As we confront these challenges, it is crucial to recognize the broader significance of coral reefs, not only for biodiversity but also as vital sources of income and coastal protection.

In essence, the call for conservation is not just an environmental responsibility but a necessity for the well-being of our planet and its inhabitants. The urgency of addressing CO_2 impacts on coral reefs demands immediate and sustained efforts to ensure the preservation of these invaluable ecosystems for generations to come.

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